# Rapid Variations in the Solar Atmosphere

## Introduction

The extensive theoretical work on chromospheric and coronal heating has produced two main classes of theory. The first holds for current dissipation following reconnection events in the form of flare, microflare and nanoflare activity, while the second suggests that heating is driven by MHD waves which propagate from the lower atmosphere or are triggered by impulsive events (Priest & Schrijver 1999). The search for observational evidence, as to dictate which theory holds in localised spatial and temporal dimensions, requires multi-wavelength data at high-spatial and temporal resolution of a large number of events. The observing time requested in this proposal will use a visitor instrument (RDI; see below) to provide the optical component of such a dataset.

## Wave Heating

The investigation of wave phenomena in the solar atmosphere has increased dramatically in recent years with the study of quasi-periodic oscillations benefiting enormously from wavelet analysis techniques (e.g., Bloomfield *et al.* 2004b) which are better suited for the identification of transient oscillations than traditional Fourier analysis. Ground-based observations, combined with space-borne instruments, have provided information for new theoretical developments that link the observations with certain oscillatory modes. These include compressible waves in solar plumes (de Moortel & McAteer 2005), damped slow mode waves from impulsive events (Ofman & Wang 2002), flare generated kink modes in the EUV (Aschwanden *et al.* 1999) and fast mode magneto-acoustic waves travelling through coronal loops (Williams *et al.* 2002). Oscillations in network bright points have been detected at various heights in the solar chromosphere and revealed evidence for mode coupling which occurs when transverse waves transfer power to longitudinal waves. The evidence for this important finding was revealed from our earlier Sac Peak observing runs (McAteer *et al.* 2003, Bloomfield *et al.* 2004a).

## Impulsively Generated Waves

An MHD disturbance generated at a flare site can also trigger intensity oscillations and there are several examples where oscillations at various wavelengths are associated with solar flares, e.g., Kane *et al.*. (1983) reported large amplitude pulsations (20%) with a period of $\sim$ 8 sec in hard X-rays (HXR) and microwaves, Aschwanden *et al.* (2001) has shown the first evidence for spatial oscillations in coronal loops (Fe IX) with a $\sim$ 280 sec period suggestive of resonant coupling with the photosphere. More recently McAteer *et al.* (2005) have found an oscillatory signal in H$\alpha$ (blue wing; periods of 40–80 sec) associated with a flare ribbon. The oscillation, detected during the impulsive phase of a C9.6 class flare, may be interpreted as a series of reconnection events (periodic reconnection) or a single reconnection event which sets up a wave in the loop, resulting in the periodic instensity variations. McAteer *et al.* (2005) favour the wave explanation as this also accounts for the dropoff in oscillatory power during the decay phase of the event. The identification of the mode of oscillation from observations has led to the development of *atmospheric seismology* whereby the oscillations are used to deduce the characteristics of the plasma in which the waves exist (Roberts *et al.* 1983, Nakariakov *et al.* 1999).

## Flares, Microflares, & Nanoflares

In solar flares, non-thermal electrons heat the chromosphere via Bremsstrahlung interactions. The short time scales associated with this are a natural consequence of the intermittent nature of these events and are evident throughout literature, e.g., Kiplinger *et al.* (1983) report short duration spikes ($\sim$ 0.04 sec) associated with the HXR emission of solar flares and the spectra of these bursts are consistent with models of non-thermal electron beams (Kiplinger *et al.* 1984). Electron beam heated solar flare models show that H$\alpha$ is a good tracer of rapid fluctuations where fast variations ($<$ 0.1 sec) arise as a result of the energy imbalance, while slower variations ($>$ 0.5 sec) are the result of ionization imbalance and chromospheric condensation. The ionization timescales are determined by the intensity of the non-thermal flux deposited in the chromosphere (Fisher, Canfield & McClymont 1985, Canfield &

Gayley 1987). Hence high cadence optical observations are a vital addition to HXR data. In respect to the current solar minimum, this support data is vital as RHESSI is expected to be in attenuator state A0 hence maximising sensitivity in the 3–15 Kev range.

**Instrumentation**

We propose to use the DST equipped with the visitor instrument RDI (Rapid Dual Imager) and the UBF or Zeiss-alpha filter. RDI can achieve a temporal sampling of up to 60 frames per second simultaneously in two cameras (ran from one clock to ensure synchronicity). One of the cameras will observe in H$\alpha$ (either the core or the blue wing) while the second camera will observe in the G-band. The G-band images will be used to monitor for photospheric changes as well as the de-stretching of the H$\alpha$ images. In order to maximise the multi-wavelength aspect of the study we will observe the designated Max Millennium observing target (one of us, James McAteer, will be the designated Max Millennium chief observer during the observing period) which is commonly observed by TRACE and instruments onboard SoHO.

Our observing program and primary objectives can be summarised as follows:

- Theoretical evidence suggests that high-frequency oscillations ($\nu > 0.5$ Hz) are required for MHD waves to be a viable source of atmospheric heating (Porter *et al.* 1994, Williams *et al.* 2002). We propose to search for these frequencies in active regions. The proposed high time and spatial resolution will allow us to identify whether the quasi-periodic variations observed are associated with a wave or are the result of repeated reconnection events.

- Investigate the spatial and temporal evolution of H$\alpha$ core (or blue wing) variations in solar flares and microflares and compare them with the time profiles of HXR bursts, via co-temporal RHESSI data. The H$\alpha$ observations will allow us to identify the electron precipitation sites of the non-thermal electrons that produce the HXR bursts.

- Depending on the solar activity level and flaring probability of the chosen active region we may observe in either H$\alpha$ core or blue wing so as to concentrate on one of the above objectives. However, both objectives will be covered and studied to determine which heating mechanism may dominate in the local spatial and temporal domains.

**Visitor Instrument - Technical Information**

RDI (Rapid Dual Imager) is a CCD camera system designed to provide synchronised high time resolution observations at a maximum cadence of 60 frames per second in two cameras. This instrument is an upgraded version of SECIS (Solar Eclipse Coronal Imaging System), initially tested using the NSO Evans Solar Facility coronagraph (Phillips *et al.* 2000) and successfully used in the Bulgaria 1999 and Zambia 2001 total solar eclipses (Williams *et al.* 2001, 2002) as well as at the Big Bear solar observatory (McAteer *et al.* 2005).

RDI comprises of two Basler A301b 10 bit, C-mount, 658×494 pixel cameras with a pixel size of 9.9×9.9 microns. The cameras are monochromatic with a peak response at 5000 Å dropping to 60% at H$\alpha$ and to 50% at 4000 Å. Further details are in the attached document. A high-end PC includes custom software for synchronising and collecting the data, using an IDE RAID array. Preallocated harddrive space is filled at a maximum rate of 31 MB $s^{-1}$ onto a 120 MB partition for each camera. This allows an uninterrupted data stream of over 2 hours, although a full day of observations can be stored by windowing the CCD chip and/or decreasing the cadence. The PC also acts as a FITS converter and the resulting data is stored on dual-layer DVDs overnight, allowing data to be deleted from the PC in preparation for the next day's observations.

Equipment to be transported to NSO/Sac Peak – The cameras, electronics, connecting leads, computer and DVDs. This equipment will arrive at the DST well in advance of the observing run and the shipping will be fully financed by Queen's University Belfast. One observer will arrive a few days before the start of the run to test the RDI equipment with a second observer arriving the day before the beginning of the run. We emphasize that the cameras and data acquisition unit is stand-alone and does not need any interface with the telescope control system. We envisage leaving the equipment (i.e., cameras, electronics, computer) at NSO for other scientists to use if desired.

Equipment required from NSO – We require beam-splitters, lenses and transfer optics to provide images at optimum resolution. RDI has no associated optics and therefore requires an AO stabilised beam focused on each of the two cameras.

Estimated engineering support from NSO – Mounts to connect the cameras to the observation table (including fine tuning for focusing) are required. We request some engineering support/mechanical machinist time for this. We estimate that it will take approximately two days to built the camera mounts. Camera dimensions and mounting information is available on the attached document.

**Recent refereed publications from data taken at the DST within the last 2 years:**

• Bloomfield, D.S., McAteer, R.T.J., Mathioudakis, M., Keenan F.P.,
*Spectroscopic observations of oscillations in the solar network*, in preparation

**Other publications including data taken at the DST:**

• Bloomfield, D.S., McAteer, R.T.J., Lites, B.W., Judge, P.G., Mathioudakis, M., Keenan F.P.
*Wavelet Phase Coherence Analysis: Application to a Quiet-Sun Magnetic Element*,
2004b, ApJ, 617, 623

• Bloomfield, D.S., McAteer, R.T.J., Mathioudakis, M., Williams, D.R., Keenan F.P.
*Propagating Waves and MHD Mode Coupling in the Quiet-Sun Network*,
2004a, ApJ, 602, 436

• McAteer, R.T.J., Gallagher, P.T., Williams, D.R., Mathioudakis, M., Bloomfield, D.S., Phillips, K.J.H., Keenan, F.P.
*Observational Evidence for Mode-Coupling in the Chromospheric Network*,
2003, ApJ, 587, 80

• McAteer, R.T.J., Gallagher, P.T., Williams, D.R., Mathioudakis, M., Phillips, K.J.H., Keenan, F.P.
*Long-Period Chromospheric Oscillations in Network Bright Points*,
2002, ApJ, 567, L165

**References**

Aschwanden, M.J., *et al.* 1999, ApJ, 520, 880
Canfield, R.C., & Gayley, K.G. 1987, ApJ, 322, 999
Fisher, G.H., *et al.* 1985, ApJ, 289, 425
Kane, S.R., *et al.* 1983, ApJ, 271, 376
Kiplinger, A.L., *et al.* 1983, ApJ, 265, L99
Kiplinger, A.L., *et al.* 1984, ApJ, 287, L105
de Moortel, I., & McAteer, R.T.J. 2004, Sol Phys, 223, 1
McAteer, R.T.J., *et al.* 2005, ApJ, 620, 1101
Nakariakov, V.M., *et al.* 1999, Sci, 285, 862
Ofman, L., & Wang, T. 2002, ApJ, 580, L85
Phillips, K.J.H., *et al.* 2000, Sol Phys, 193, 259
Priest, E., & Schrijver, C.J. 1999, Sol Phys, 190, 1
Roberts, B., *et al.* 1983, Nature, 305, 688
Williams, D.R., *et al.* 2001, MNRAS, 326, 428
Williams, D.R., *et al.* 2002, MNRAS, 336, 747